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Lodgepole Pine Commercial Forests: an Essay Comparing the Natural Cycle of Insect Kill and Subsequent Wildfire With Management for Utilization and Wildlife

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The Author

Peter Koch, now 76 years old and president of Wood Science Laboratory, Inc. in Corvallis, MT, is one of the 20th century's most eminent scientists in wood technology.

His research activities in industry and government, extending over more than 35 years, have yielded major contributions including development of the headrig chipper—a technology now extensively used worldwide, pioneering work on high-temperature drying of southern pine lumber—a methodology now in broad use, early determination of practical methodologies for manufacturing southern pine plywood—today a major commercial commodity, pioneering research on the virtues of laminated-veneer lumber and fabricated joists, and development of a feasible and profitable method for using dense southern hardwoods as furnish for structural flakeboard.

His two major treatises written while directing the USDA Forest Service utilization laboratory of the Southern Forest Experiment Station—*Utilization of the Southern Pines* (two volumes; 1972) and *Utilization of Hardwoods Growing on Southern Pine Sites* (three volumes; 1985)—are standard texts on the species. Earlier, in 1964, Ronald Press published his textbook *Wood Machining Processes*.

In 1972 to 1973, Koch served as President of the Forest Products Research Society. In 1974 he was elected Fellow in the International Academy of Wood Science. In 1982 he was elected Fellow in the Society of American Foresters. Other recognitions of the esteem in which he is held by his profession include an honorary doctor of science degree from the University of Maine, a John Scott Award, a Woodworking Digest Award—both for invention of the headrig chipper, a Forest Industries Award for excellence in raising sawmill/plywood plant efficiencies, a Distinguished Service Award from the Society of Wood Science and Technology, and the Fred W. Gottschalk Memorial Award for outstanding service to the Forest Products Society.

After a brief tenure with the Intermountain Research Station in Missoula, MT, he retired from the USDA Forest Service in 1985 to form the corporation Wood Science Laboratory, INC., Corvallis, MT, of which he is president. Additionally, he is currently Distinguished Affiliate Professor in the Department of Forest Products of the University of Idaho, Faculty Affiliate in the School of Forestry of the University of Montana, and Concurrent Professor of the Nanjing (China) Institute of Forestry.

His continued interest in the field of forest products research has recently been expressed by an endowment he (with his wife Doris) established by a substantial gift to the Forest Products Research Society, Madison, WI.

In addition to his professional activities, Koch has been active throughout his life exploring rivers of North America by canoe and raft, piloting aircraft over long distances (including near circumvention of the globe), traveling the world's continents, and trekking mountainous terrain in both North and South America. He is an avid fly fisherman, and until recently winter weekends found him with Doris downhill-skiing on the Montana-Idaho divide of the Bitterroot Mountains.

Most recently, his 13-year effort (1982-1995) jointly supported by the USDA Forest Service Intermountain Research Station and Forestry Canada, with cooperation by the University of Montana, yielded the three-volume text: Koch, Peter. 1996. *Lodgepole Pine in North America*. Madison, WI: Forest Products Society. 1096 p. ISBN 0-935018-78-6. This general technical report is an essay distilled from those 13 years of research on lodgepole pine and from analysis of the 6,300 papers on the subject collected in his library.

Research Summary

Lodgepole pine (*Pinus contorta* Loud.), particularly the subspecies growing in the Intermountain and Rocky Mountain Regions (ssp. *latifolia*), is a major economic asset of both the United States and Canada. In the United States, the lodgepole pine timber type is the fourth most extensive west of the Mississippi River and occupies about 6 million ha of commercial forest land. In Canada the lodgepole pine forest type occupies about 20 million ha, mostly in British Columbia and Alberta.

In persistent and climax lodgepole pine stands, where other tree species do not prosper, this light-loving species languishes or dies as an understory but is thrifty in spaced even-age stands. When grown to diameters over 25 cm or to tree ages exceeding 80 years, lodgepole pine in persistent or climax stands is at high risk of mortality from mountain pine beetle attack and subsequent stand-replacing wildfire. The 1988 wildfires in Yellowstone Park, and other fires in Montana, Washington, and Idaho in 1994, illustrate this natural cycle.

Healthy stands are best maintained by precommercial cleaning of overdense regeneration (at about 10 years of age) to a prescribed stocking density, intermediate commercial thinning at perhaps age 30 years, and clear-cut harvesting before age 80 years. In persistent and climax stands of lodgepole pine so managed on commercial timberlands of North America, water yields and quality, forage yields, and recreational values need not be more at risk than they are from insect-caused mortality and subsequent wildfire.

All of the perturbations—natural as well as management-related—to which lodgepole pine is subjected (mortality from insect attacks, stand-replacing wildfires, early stocking control, thinning, and clear-cut harvesting) profoundly affect wildlife habitat. In the national interests of both the United States and Canada a better understanding of the effects of these habitat changes is needed, with a goal of keeping common species common while simultaneously maintaining or recovering populations of rare or jeopardized species. Well-dispersed, intensively managed lodgepole pine stands can play an important role in avoiding large-scale disruptions of species associated with the common life cycle of lodgepole pine resulting from unmanaged bark beetle and wildfire sequences.

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Lodgepole Pine Commercial Forests: an Essay Comparing the Natural Cycle of Insect Kill and Subsequent Wildfire With Management for Utilization and Wildlife

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Introduction

Some would argue that humankind is not the center of life on the planet—but it is not surprising that humans pursue courses of action that they perceive as contributing to their well being. Thus, those who are unsheltered, cold, and hungry will aggressively seek to alleviate their wretched condition. Throughout human tenure on earth a plentiful supply of wood has been a source of such alleviation. Humans need wood to house themselves, to heat their habitations, and to cook their food. For these and other uses, wood efficiently satisfies important basic and aesthetic requirements for human life.

Global consumption of wood totals about 3.23 billion m^3 annually. Of this total, 53 percent is consumed as fuel, 31 percent goes into construction in all its aspects, and 16 percent is pulpwood. Not only is more than half the global wood harvest consumed as fuel, the percentage has been rising at about 0.15 percent a year over the last 20 years (Sutton 1991, based on Food and Agriculture Organization data).

In the United States, the tonnage of raw wood consumed is approximately equal to the combined tonnage consumption of all metals, cements, and plastics (data from authoritative Federal and industrial sources).

The growing population of North America and the world in general, and the growing per capita consumption of wood in the world—0.60 m^3 in 1950, 0.67 m^3 in 1989, and 0.70 m^3 projected in 2010 by The Food and Agriculture Organization of the United Nations (Sutton 1991)—strongly suggest that forests should be expanded with concomitant intensification of management for sustainable yields. We in North America, endowed as we are with extensive and productive forests, cannot in good conscience shift the burden of supplying our needs for wood to less-well-developed countries.

I believe sustainable forestry involves perpetuation of essential ecological processes, while also providing goods and services essential to meeting human needs. To gain consensus acceptance of sustainable forestry, such forestry must be:

- Individually and societally gainful, and economically practical
- Biologically possible
- Culturally acceptable

In many ways, satisfaction of the last-named requirement is the most difficult, but it should be less difficult with lodgepole pine-type forests than with some other forest types. To begin with, more than half of the lodgepole pine resource in the United States, and virtually all of the lodgepole pine in Canada, lie within the area covered in fairly recent geologic time by massive aggregations of continental ice, with the last recession of this ice occurring only about 12,000 years ago. Hence, our present lodgepole pine-type forests have become established in relatively recent times. Additionally, the preponderance of lodgepole pine naturally occurs in pure, more or less even-age stands, with most stands aged 100 years or less. For example, the 1984 inventory of Alberta lodgepole pine (Alberta Forest Service 1985) indicated that 90 percent of the lodgepole pine volume in natural unharvested stands was less than 120 years old.

Most of these relatively young, even-age stands have resulted from periodic wildfires—frequently following high mortality from bark beetle attacks. Since 1650 in forests west of the Continental Divide in Montana's Glacier National Park, for example, wildfires ranging from nonlethal underburns to stand-replacing fires have occurred at intervals from 25 to 75 years, and stand-replacing fires have occurred at intervals of from 140 to 340 years (Barrett and others 1991).

While biological diversity is considerable over the entire range of the species, at any particular location the diversity is less than in some other forest types.

For all these reasons (frequency of mortality from insect attack, frequency of stand-replacing wildfires, natural tendency toward young single-species even-age stands, and modest within-stand biological diversity) human intervention intensifying management to

increase forest yields need not greatly, nor particularly adversely, alter the natural rotation that results from repeated and frequent cycles of insect infestation and wildfire.

The Resource

If one were to take off in an airplane from southern Colorado in the United States, climb to about 3,000 m adjacent to the Continental Divide, and put the airplane into a 3,200 km glide following the Rocky Mountains northwest while descending to about 900 m into the southern portion of Canada's Yukon Territory, one would skim the top of a nearly continuous forest of lodgepole pine (*Pinus contorta* Dougl. ex Loud.—or by more recent convention, *Pinus contorta* Loud.). This south to north range from about 37° (31° at one location in Baja California) to about 64° of north latitude coupled with an east-west range from the Pacific Coast to the Black Hills of South Dakota makes lodgepole pine one of the major timber types of North America.

In the United States, where it is the fourth most extensive timber type west of the Mississippi River and the third most extensive in the Rocky Mountains, the species occupies about 6 million ha of commercial forest land containing about 748 million m^3 of lodgepole pine growing stock—trees 12.7 cm diameter at breast height (d.b.h.) and larger to 10.2 cm top diameter outside bark—and over 71 billion board feet of lodgepole pine sawtimber—trees to 17.8 cm top diameter outside bark. This growing stock occurs mostly in Montana, Idaho, Wyoming, Colorado, Oregon, and Washington. Canada has a much greater acreage of lodgepole pine forest type than the United States—about 20 million ha, mostly in British Columbia and Alberta. It comprises 22 percent of the total forest in western Canada. This acreage carries about 1.3 billion m^3 of merchantable timber.

Much of this total area sits astride the Rocky Mountains and the Sierra Nevada where both recreation and livestock husbandry are major industries, where protection of water supply and quality is of vital concern, where wildlife species—particularly big-game animals—abound, and where headwater streams carry abundant fish populations.

Energy Considerations: Entropy and the Carbon Cycle

To slow the increasing consumption of wood in the world and in the United States it would be possible to make significant shifts to consumption of nonwood materials. However, compelling reasons exist to resist such shifts. First, wood as a structural material contains much less embodied energy than competitive nonwood materials and requires far less consumption of fossil-fuel energy for extraction and manufacture. Second, the manufacture and use of wood for structural and architectural purposes releases significantly less carbon dioxide to the atmosphere than the manufacture of most substitute nonwood materials. Third, entropy of the world's energy system is less adversely affected by use of wood for structural and architectural purposes than by use of most alternative nonwood materials.

The Committee on Renewable Resources for Industrial Materials (CORRIM) report (Boyd and others 1976), to which I was a major contributor, was an early and important major analysis of energy embodied in alternative construction materials in residential and light commercial buildings. The report dealt with energy required to extract materials from ground or forest, fabricate the materials into useful form, and transport the resulting building materials to the construction site. The CORRIM report did not consider building maintenance requirements; neither did it analyze the lifespan of buildings built of the various materials and the energy required to dismantle the buildings at the end of their useful life and to recycle the salvage into other useful products (or consign the salvage to fire or landfill). In spite of its shortcomings, this report clearly showed the energy advantage of wood over important competitive nonwood structural materials.

Later, I reviewed the CORRIM report and from its data derived comparative carbon dioxide discharges to the atmosphere as related to the materials from which buildings are constructed—again showing the advantage of wood compared to most competitive structural materials (Koch 1992). The papers presented at the June 1995 meeting of the Forest Products Society in Portland, OR, further explored some of the issues raised by the CORRIM report and by subsequent lifecycle analyses.

While it is obvious that both forests and wood products temporarily store carbon, it is equally obvious that such storage can only buy time in the battle to restore balance between carbon additions and subtractions from the atmosphere. That is, sequestering carbon in forests and wood products cannot indefinitely offset the massive infusions of atmospheric carbon resulting from combustion of fossil fuels.

The real force driving additions of carbon to the atmosphere is the thermodynamic law of entropy, which provides a measure of change toward unavailable energy in a system. According to the law of entropy, energy in a system tends to move from available to unavailable condition. For example, a lump of

coal or liter of oil containing available heat energy can be burned to provide heat, to boil water, and produce high-temperature steam to move a piston and, by overcoming friction, drag a load over a horizontal surface. At the end of the movement, the lump of coal is reduced to ash (or the oil is consumed), heat from friction and from low temperature exhaust steam is dissipated to the atmosphere, and the load is at rest and has not changed its elevation—hence it has gained no potential or kinetic energy. That is, the available energy in the coal or oil is spent, the process is not reversible, and entropy of the system has increased.

Within the timeframe of humankind's likely span on earth, the lump of coal or the liter of oil in the example cited cannot be replaced. Not so with wood. Through photosynthesis driven by solar energy, a lump of wood (containing valuable energy) can easily be replaced within a single human lifespan.

Scope and Purpose of This Essay

These discussions explain the environmental advantages of using wood in structures in preference to most other materials, but the discussions omit a crucial aspect of life cycle analysis—the life cycle of the forest. It is in the forest's life cycle that significant differences in carbon sequestration and carbon dioxide emissions to atmosphere are encountered, depending on forest management regimes. Of more immediate importance are the significant differences in the availability of wood for structural and architectural purposes that result from different management regimes.

This essay addresses the latter differences resulting from two different management regimes (fig. 1) for lodgepole pine (*Pinus contorta* Loud.) and considers the effects of the two regimes on wood-product yield, water quality and erosion, forage yield, recreation, and wildlife. Effects on wildlife are emphasized because data on these effects are incomplete or lacking, and public opinion regarding forest management is profoundly affected by public perception of how alternative regimes affect wildlife.

I have noted that the lodgepole pine forest type occupies millions of hectares in Western United States and Canada (fig. 2, 3, and 4) where fish and other wildlife abound. Today, harvesting activity in these forests drastically alters habitat. Habitat in these forests is also often drastically altered on a large scale by attacks of mountain pine bark beetle (*Dendroctonus ponderosae* Hopkins) with subsequent broad-scale mortality (fig. 5 and 6) followed by stand-replacing wildfires (see previous discussion of fire frequency in "Introduction" and also fig. 7 and 8). The 500,000 ha

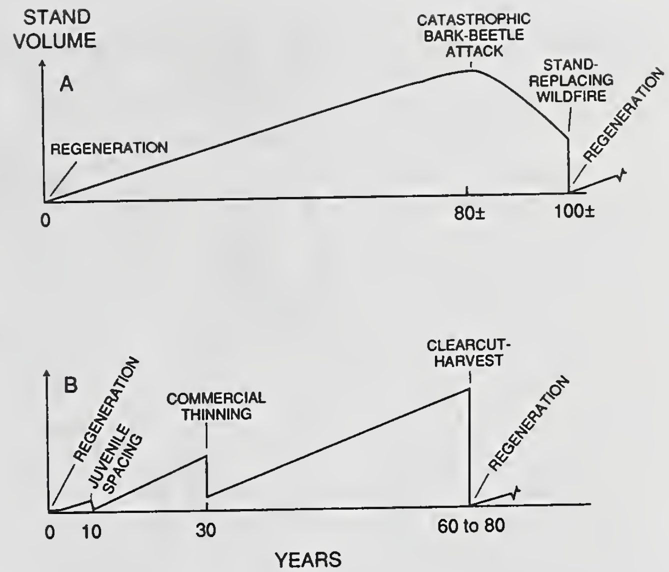

Figure 1—Schematic diagram of: (A) Common natural life cycle of climax and persistent lodgepole pine stands, contrasted with life cycle (B) of lodgepole pine intensively managed for yield of wood plus other amenities.

Yellowstone fires of 1988 and the major Montana, Washington, and Idaho fires of 1994 are examples.

The extent of mortality from attack by insects, primarily the mountain pine beetle, needs amplification. Periodically this beetle kills most of the large diameter lodgepole pines in a forest before the beetle population subsides. In northwestern Wyoming in recent years, the beetle killed about 30 percent of the trees, with proportionately more large than small trees being killed. Infestations in western Montana were more severe than those farther to the south. In an infestation on the Kootenai National Forest, for example, 94 percent of the trees 12.7 cm d.b.h. and larger were killed (McGregor and others 1987). During an epidemic a single National Forest may lose more than a million trees in 1 year; for example, 3.6 million lodgepole pines were killed in the Targhee National Forest, ID, in 1976 (Klein and others 1979). In 1970, volume loss of growing stock to mortality in the Rocky Mountain States totaled about 17 million m^3—mostly from mountain pine beetle attacks on lodgepole pine. The mountain pine beetle has killed an estimated 2 billion board feet per year since 1895 (Wood 1963).

To ameliorate or prevent such broad-scale mortality from insects, and subsequent stand combustion by wildfire, future generations of land managers responsible for lodgepole pine commercial forests will likely manage them increasingly intensively because of their high value for wood, water, forage, wildlife, and recreation.

Figure 2—Occurrence of significant volumes of lodgepole pine forest type in the United States. The case study sites are discussed in Koch and Barger (1988).

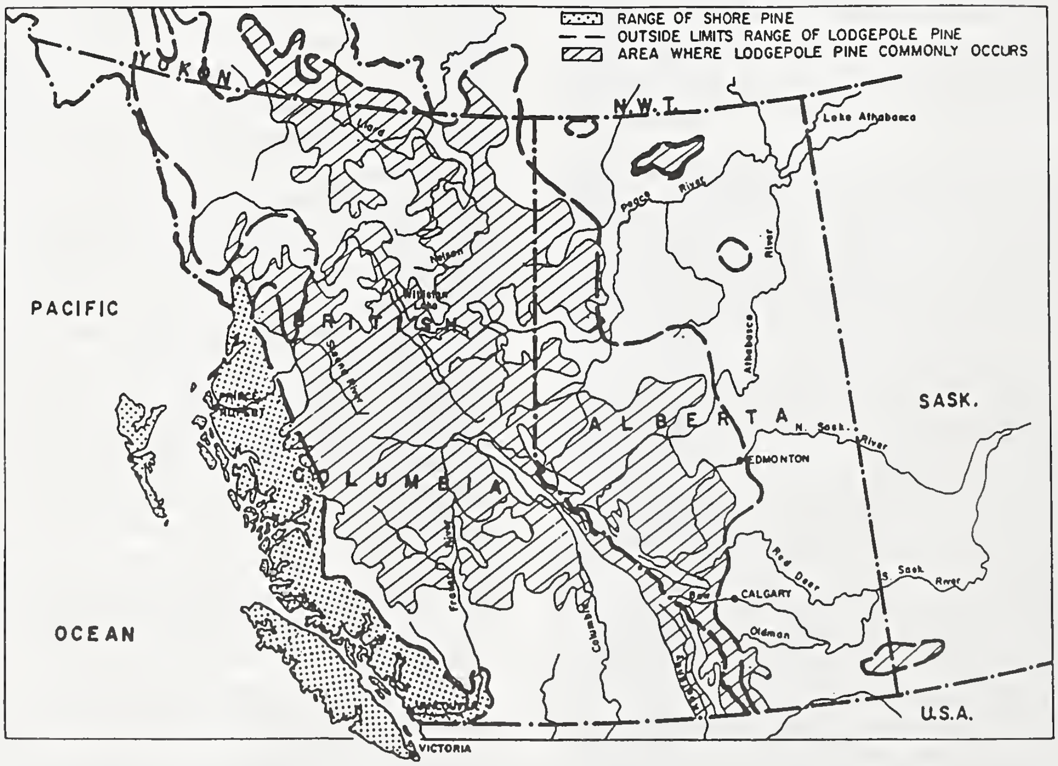

Figure 3—Canadian range of lodgepole pine ssp. *contorta* and *latifolia* with areas of common occurrence of *latifolia* indicated. Drawing after McDougal (1975).

Figure 4—Relative volumes of stemwood of lodgepole pine growing stock on timberlands in the Western United States, and approximations for lands in British Columbia, Alberta, and the Yukon Territory. The bar shown for Montana represents 259 million m³. Growing stock is the net cubic volume of stemwood in live trees 12.7 cm in d.b.h. and larger, from 30-cm-high stump top to a minimum 10.2 cm top of central stem outside bark or to the point where the central stem breaks into limbs.

On sites where lodgepole pine is a climax species, or can be managed as a climax species, overdense natural regeneration will be precommercially thinned at about age 10 years (fig. 9), and at about age 30 years resulting stands will be commercially thinned for roundwood products (fig. 10 and 11), with final clear-cut harvest (fig. 12) before stand age 80 years to avoid catastrophic mortality from bark beetle attacks. By this time they will have attained stand d.b.h. close to, but intentionally not in excess of, 25 cm. Ultimately, genetically improved seedlings will supplant natural regeneration on some of the most favorable sites.

I recognize that management of lodgepole pine is a controversial subject. To bring some perspective to the controversy, this essay compares two alternative life cycles in climax on persistent forests of lodgepole pine—that is, the natural cycle of insect-caused mortality followed by wildfire (fig. 1A) which is repeated about every 100 years (often less frequently, but sometimes more frequently), and the intensively managed cycle involving thinning and harvest (fig. 1B), which is designed to avoid catastrophic bark-beetle attack and subsequent stand-replacing wildfire.

Clear-cut harvesting imperfectly mimics wildfire. Clearcuts with retention of 10 to 20 percent standing and down lodgepole pine biomass would more closely approximate wildfire effects. Unfortunately, however, lodgepole pine subjected to partial or patch cutting is highly susceptible to windthrow. And if mistletoe infection is present, regeneration is threatened by residual infected trees.

Lodgepole pine is a thin-barked species—a light-loving tree that languishes or dies as an understory. Controlled underburning is seldom if ever a viable option to forestall stand-replacing wildfires in persistent or climax lodgepole pine forests. Unlike in stands of ponderosa pine or the southern pines, even ground fires of relatively low intensity within lodgepole pine stands will cause major mortality, or at least cause degrading and disease-promoting fire scars and increased susceptibility to attack by bark beetles. For a discussion of the natural role of fire and fire management options in some different lodgepole pine types, see Bradley and others (1992). For discussion of constraints on prescribed fire and broadcast burning following harvest, as related to regeneration, see Koch (1996, p. 170).

Lodgepole pines need not be burned by wildfire to regenerate naturally, as some would suppose. Harvest procedures that position serotinous (closed) cones closely adjacent to sun-warmed soil will accomplish cone opening and seed dispersion with equal efficiency (Clark 1983; Ferdinand 1983; Lotan and Critchfield 1990). As Charles Lamb observed in his 1822 *Dissertation on Roast Pig*, one need not burn down the hog house to roast a pig—although it took the local population in the period he described some time to come to that conclusion.

Whether regenerated by wildfire or harvest, forests of lodgepole pine need available soil nutrients sufficient to yield foliar nutrient contents (percent of dry mass) about as follows: nitrogen, 1.4 to 1.55 percent; phosphorus, 0.14 to 0.17 percent; potassium, 0.50 to

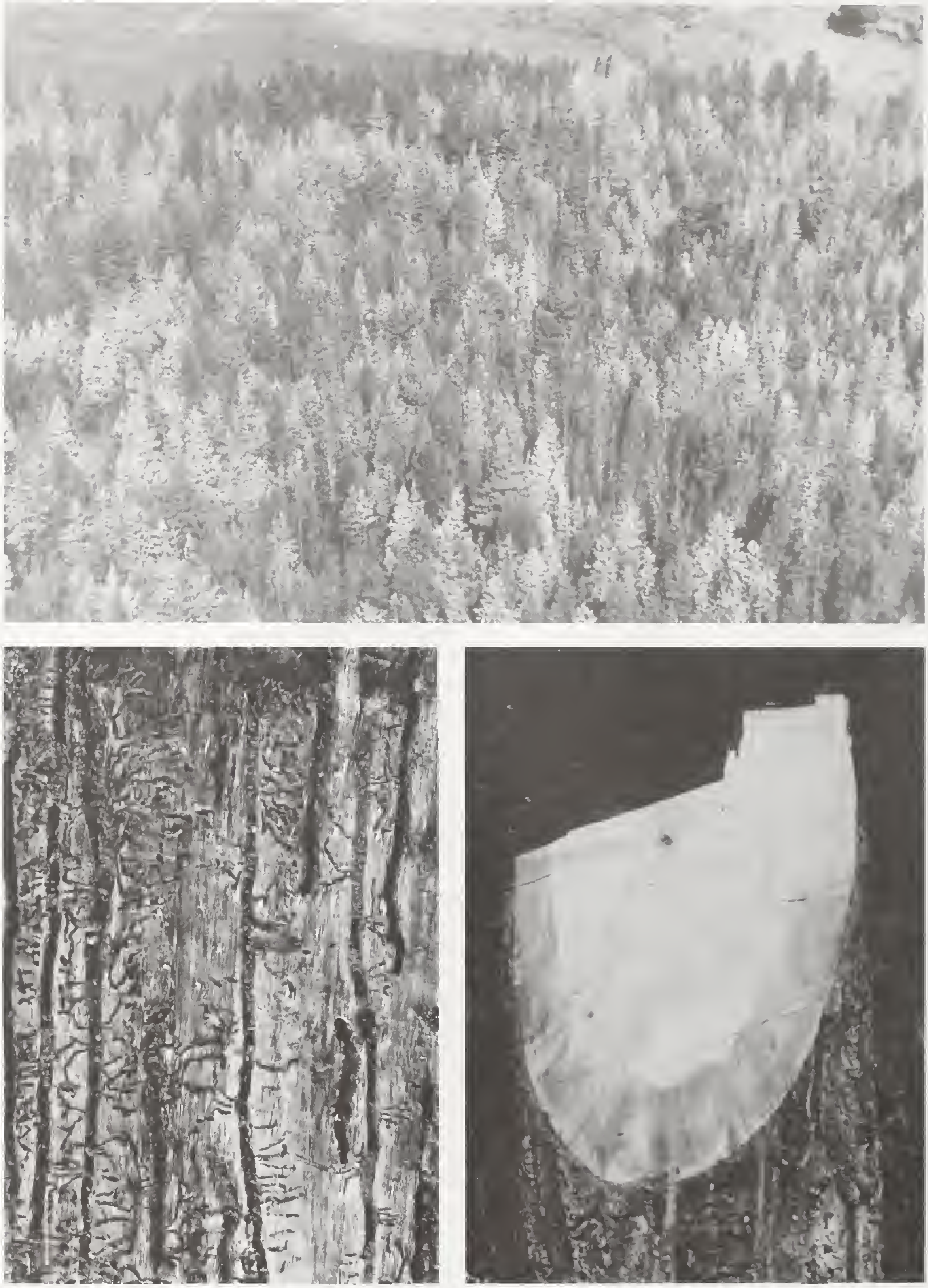

Figure 5—(Top) A lodgepole pine stand near Nine-Mile, MT, under attack by mountain pine beetles. Light-colored crowns indicate dead trees. (Bottom left) Winding egg galleries made by mountain pine beetles in inner bark of lodgepole pine. (Bottom right) Blue stain introduced into sapwood by mountain pine beetles. Photos courtesy of Gene D. Amman.

Figure 6—A stand of dead lodgepole pine sawtimber in Montana. The trees were killed by mountain pine beetles. Photos courtesy of Gene D. Amman.

Figure 7—Fire-killed lodgepole pine. (Top) Pole stand. (Bottom) Stand of small-diameter sawtimber in Yellowstone National Park 2 years after the 1988 wildfires. Photos courtesy Richard C. Rothermel.

0.60 percent; calcium, 0.10 percent; and magnesium, 0.09 to 0.10 percent. Additionally, soils need trace amounts of manganese, copper, boron, and zinc (Weetman and others 1985). If soils are deficient, such nutrients can be supplied to commercial forests by application of fertilizers. Need for supplemental nutrients can be minimized by delimbing at the stump during harvest so that green foliage and twigs are distributed over the harvested acreage.

Focus

Managers of U.S. National and Canadian Provincial Parks and of designated wilderness areas have obligations and agendas that differ from those of managers of commercial forests.

My concern is sharply focused on commercial forests—including what the U.S. Forest Service calls timberlands—that is, forest land that is producing or

Figure 8—Fire-killed lodgepole pine in Yellowstone National Park 2 years after the 1988 wildfires. (Top) Stems broken by a downburst of air from a convection column. (Bottom) Charred and checked stems. Photos courtesy of Richard C. Rothermel.

that is capable of producing crops of industrial wood, and not withdrawn from timber utilization by statute or administrative legislation. Areas qualifying as timberland are capable of producing in excess of 20 ft^3 per acre per year (1.4 m^3 per ha per year) of industrial wood in natural stands.

To focus even more sharply, the lodgepole pine forests of concern here are only those that are climax or can be managed as climax forests. Such stands can be described as follows:

- **Persistent**—Lodgepole pine forms the dominant cover type of even-age stands with little evidence of replacement by shade-tolerant species, which occur only as scattered individuals and are apparently too few and lack sufficient vigor to replace lodgepole pine. Lodgepole pine maintains its dominance either because of inadequate seed source for potential competitors or because sites are poorly suited to other species.

Figure 9—Ssp. *latifolia* stand of fire origin after precommercial selection cleaning (juvenile spacing) on Upper Pelton Creek of the Medicine Bow National Forest in Wyoming. Distance between the two trees in the foreground is about 2.5 m.

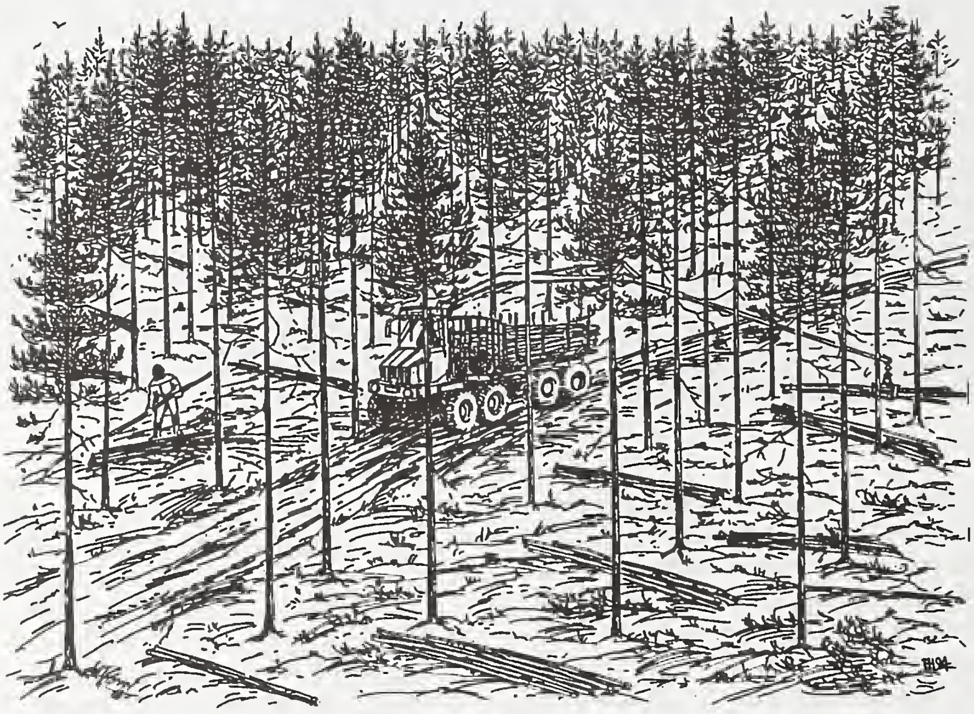

Figure 10—Forwarder retrieving cut-to-length roundwood in a thinning operation. Drawing by Pirkko Hakkila.

Figure 11—Lodgepole pine stand near Condon, MT, being thinned to 3.7 m spacing at age 35 years (yielding roundwood products), thus drastically altering within-stand microclimate and reducing risk of attack by bark beetles. Photo courtey of Dennis M. Cole.

Figure 12—Clearcutting is compatible with the silvical requirements of lodgepole pine and is the preferred regeneration harvest method in most climax or persistent lodgepole pine forests.

- **Climax**—Lodgepole pine is the only species capable of growing on particular sites and is self-perpetuating. In some areas it is an edaphic climax in frost pockets. In others it is an edaphic climax on granitic soils and on shallow infertile soils of schist origin. It also forms an edaphic climax on obsidian sands in the West Yellowstone Basin of the Gallatin National Forest.

Thus, by the nature of the species and under these circumstances, these forests—while exhibiting great genetic variation—are essentially even-age monocultures of overstory trees. Major components of understory vegetation can include dwarf huckleberry, bitter brush, twin flower, grouse whortleberry, pinegrass, bear grass, mosses, liverworts, and lichens depending on habitat type and stage of stand development.

Forests of the lodgepole pine type obviously contain stands more diverse than those just described, but it is particularly in these **persistent** and **climax** commercial stands that the risks of bark-beetle attack and subsequent stand-replacing fires need to be countered with intensive forest management including density control of regenerated stands and intermediate thinning to attain trees of about 25 cm d.b.h. for clear-cut harvesting before age 80. This statement implies that for such commercial forests, a major management goal is production of wood for human use.

During dry summers I often see, from my study windows in western Montana, smoke from half a dozen wildfires in unmanaged lodgepole stands containing large components of dead timber. During a bad fire year, thousands of firefighters are deployed on such fires, with concomitant low-level air traffic and retardant dumps, and construction of extensive fire lines and bulldozer access trails. Annually, thousands—sometimes millions—of hectares of lodgepole pine timber are fire-consumed in North America. In time, this land is recycled by nature to younger stages of forest, but vast volumes of wood useful to humans are irrevocably lost in the process.

Product Yields From Intensively Managed Stands

The management of growth and yield of a lodgepole pine forest is not only profoundly complex, it is also controversial. The fundamental premise of traditional forestry—that scientific management for wood production is good for both people and forests—has been challenged in recent years by those with an entirely different view. Contributing to the complexity and controversy are the multitude of management choices concerning desired products or values of the forest. If wood production is the primary objective, what form and quality of wood—and with what timing? If water yield is the primary object, what are the end uses (human consumption, fish habitat enhancement, irrigation, hydroelectric power generation, aesthetic and recreational considerations), and what are the requirements for volume and timing? If wildlife and fisheries protection or production is the objective, what are the species and what are their needs? If pasturage of domestic animals in the forest is an objective, what are the needs for forage and cover? If aesthetic and recreation considerations rule, what manner of access and what quality, structure, and scale of landscapes are desired?

Because I believe that in the long run management programs must be biologically possible, socially acceptable, and individually and societally gainful from an economic point of view, a major objective may be to maximize short-term and long-term monetary return to forest owners and to individuals of communities supported by forest-related enterprises.

To simplify analysis, in this text section I discuss only aspects of wood production. Other management considerations are discussed in following sections.

With growth and yield defined in terms of wood production, obviously managers are faced with the need to decide at the outset—or at least retain sufficient flexibility in management plans to decide later—what the products of the forest are to be. A partial list of product options, all strongly affecting management for growth and yield, include fuel, chemicals, fiber for paper and board products, lumber and plywood, and roundwood products.

If we place emphasis on wood for lumber, more questions need to be resolved. What is the desired form of the log to yield the lumber desired? What maximum knot size is tolerable, and what are tolerable limits of specific gravity, compression wood content, and spiral grain? A different way of phrasing the question: Is the wood to be used for decorative purposes, as structural wood demanding uniform high strength, as industrial lumber in which grade is of minor importance, as wood in large dimensions, or as wood in small pieces to be fabricated into larger components?

These are not questions easily resolved. For added perspective, the following tabulation shows some historic developments in the use of wood over the last 100 years—a span somewhat commensurate with rotation age of a lodgepole pine forest.

Major wood products	Product in significant use? 1900	2000
Ship masts	yes	no
Charcoal for smelting	yes	no
Sheathing boards for floors and roofs	yes	no
Wooden boxes for fruit and vegetables	yes	no
Wooden skis	yes	no
Solid-wood lumber panelling	yes	limited
Wood shingles and shakes	yes	limited
Wood producer gas	yes	limited
Ethanol	no	limited
Rayon	no	limited
Kraft-process paper from pines	no	yes
Paperboard packaging	no	yes
Wood treated with preservative CCA	no	yes
Structural plywood	no	yes
Hardboard fiberboard	no	yes
Medium density fiberboard	no	yes
Molded composites of wood and other fiber	no	yes
Particleboard	no	yes
Structural beams glue-laminated from lumber	no	yes
Structural lumber laminated from veneer	no	yes
Structural flakeboard	no	yes
Structural lumber from strands	no	yes
Pallets for fork-lift material handling	no	yes
Plate-joined light frame trusses	no	yes
Lumber nondestructively strength-classified	no	yes
House logs, poles, fence posts, and rails	yes	yes
Solid wood floor joists, studs, and planks	yes	yes
Joinery wood	yes	yes
Wood for fuel	yes	yes

This tabulation suggests that forest managers have no way of predicting what technological changes in wood product form will occur during the next 80 years when trees that are regenerated today may be harvested. This uncertainty about technological change is one force driving the desire for short rotations. As with any investment in which initial costs grow exponentially with time by annual compounding, a prevailing high interest rate is a potent force working to shorten rotations. And in the case of lodgepole pine, the risk of catastrophic losses from bark beetle attacks on trees measuring greater than about 25 cm d.b.h. is a third force driving need for short rotations. Researchers in both the United States and in British Columbia have observed an interaction between age, tree diameter, and bark beetle risk. Some evidence shows that at tree age near 80 years, changes in quantity and composition of stem resin make older trees susceptible to attack (Safranyik and others 1975; Shore and Safranyik 1992; Shrimpton 1973a,b). Thus, trees as small as 15 to 20 cm d.b.h. may be at risk if over 80 years old. Opposing these driving forces favoring short rotations are some of the factors discussed subsequently.

Because high-value solid wood products such as millwork, structural lumber, and structural plywood can only be made from trees of size sufficient to yield sawn lumber or veneer, it would seem prudent to manage not for maximum tonnage per hectare, but for maximum product value realized per hectare. This implies that target crop trees should have small sound knots, be about 25 cm d.b.h., and have average annual growth-ring width in the range from 1.5 to 2.5 mm. If much larger in diameter they will be at great risk from bark beetles, and if much faster grown they will have a greater juvenile wood content and will therefore probably yield lumber less stiff and strong than desired for structural purposes. Management for this size class will retain considerable flexibility to switch major emphasis to fiber, particle, or chemical output, rather than solid wood output, should technology change so demand. Moreover, rotations will not be unduly long, and tonnage yields per hectare, while not the maximum possible, can still be toward the high end of the yield spectrum.

Because demand for house logs and for posts and rails for fencing has existed since frontier days in the West, and the demand has grown significantly in recent decades, the demand for these products will probably continue for another century. And in recent years, there has developed a usually strong market for pith-centered dowels for agricultural use as tree and vine stakes. These dowels are predominantly 2 inches (5 cm) in diameter and 6 to 10 feet long, but mostly 8-feet (2.5 m) long.

The house-log market will likely be met from saw-log timber of exceptionally good form and large diameter (180 mm minimum)—with beetle-killed trees dried on the stump preferred.

The post market may be satisfied from saw-timber tops, although the market prefers wood with less taper from stagnated stands (sapwood is easily treated, but heartwood is impermeable—so dowelling is not favored). Most fence posts are 2 m long with top diameter of at least 76 mm.

The rail market has traditionally been supplied from stagnated stands, with preferred rails measuring 17 feet (5.2 m) in length and with small-end diameter of 2.5 to 3.5 inches (64 to 89 mm). Possibly it could be satisfied with pith-centered dowels 65 to 70 mm in diameter machined from stems from thinnings (which unless dowelled would have unacceptable taper). These roundwood products are among the most valuable wood products of the forest when value is expressed in dollar return per tonne of stems input to the product—usually more valuable in these terms than lumber studs, and requiring less processing costs.

Alternatively, fence-post-size lodgepole pine can be converted to valuable edge-glued millwork panels that admit sound knots (Koch and others 1989).

Simplified Cases of Growth and Yield Analysis

At the outset of this analysis, it is assumed that the stands are naturally regenerated and that the harvesting costs included the cost of accomplishing juvenile spacing of the stands at age 10 years. It is further assumed that the stands will be thinned at age 30 years for posts, tree stakes, and rails—with product yield from thinnings about sufficient to pay thinning costs. Additionally, the plantation will be managed to yield crop trees averaging 25.4 cm d.b.h. to be harvested by clearcutting before age 80 years.

Cole and Koch (1995) addressed this analysis by using a revised version of subroutine LPPIM (Cole and Edminster 1985) of the stand growth model RMYLD (Edminster 1978) to simulate managed-stand growth and yield effects. Revision of the LPPIM subroutine entailed scaling of the basal area increment equation, for the tree of average stand diameter, to recently available data from a long-term study of early spacing of lodgepole pine stands by Dennis M. Cole. Further details of the simulation can be found in Cole and Koch (1995).

Many stocking-control and thinning prescriptions were evaluated to find those that would produce an average stand diameter (root mean square d.b.h.) of 25.4 cm by age 80. With juvenile spacing at age 10 years and thinning at age 30 years, several commercial thinning prescriptions for reaching attainable rotations were found. Analysis was confined to site indexes (100 year basis) of 50, 60, and 70 feet (15.24, 18.29, and 21.34 m), as these sites predominate where lodgepole pine grows in the Northern Rocky Mountains of the United States. From these analyses, a few generalizations could be made:

- First: Regardless of the density of regeneration before juvenile spacing at age 10 years, yields of thinnings at age 30 years are maximized by juvenile spacing to about 7 by 7 feet (2.13 by 2.13 m) for sites with indexes (100 year) of 15.2 and 18.3 m, and to about 6 by 6 feet (1.83 by 1.83 m) for site index 21.3 m. This would occur while still maintaining the capability to grow crop trees at least 25.4 cm d.b.h. before age 80 years. Average tree d.b.h. at age 30 after juvenile spacing is inversely correlated with stems per acre (in range 35,000 to 2,200 stems per ha) before juvenile spacing.
- Second: These juvenile spacing regimes will yield thinnings at age 30 years with the following characteristics:

Juvenile spacing	100-year site index	D.b.h.	Height of dominants	Volume of stemwood to apical tip
m	*m*	*mm*	*m*	*m^3/tree*
2.13 x 2.13	15.2	86-107	7.0-7.3	.022-.034
2.13 x 2.13	18.3	97-117	7.9-8.2	.031-.046
1.83 x 1.83	21.3	109-117	8.8-9.1	.043-.051

- Third: Yields of roundwood products from thinnings at age 30 years of these previously described stands that have "normal" defects observed in such stands, will be about as follows:

Juvenile spacing	Site index	Trees harvested/ha	Product yield/ha
m	*m*	*No.*	
2.13 x 2.13	15.2	1,651	627 to 660 posts + 956 to 1,206 tree stakes
2.13 x 2.13	18.3	1,651	1,534 to 2,013 posts + 413 to 543 tree stakes
1.83 x 1.83	21.3	2,249	2,698 to 2,901 posts + 608 to 625 tree stakes

On site 21.3 m only, yield can include some 5.2 m rails, with corresponding decrease in post yield, as follows: 2,160 to 2,249 posts + 269 to 292 rails + 608 to 625 tree stakes.

- Fourth: If the stands have less defect than observed "normal," then product yields will be significantly greater than those just tabulated.
- Fifth: When thinned at age 30 years to the densities specified below by removing every other row in both directions, the previously described stands will yield crop trees 25.4 cm in diameter in less than 80 years, as follows:

Tree characteristic	Site index (100-year basis) 15.2 m	18.3 m	21.3 m
Stand density			
After thinning (trees/ha)	549	549	741
After mortality to 25.4 cm d.b.h. (trees/ha)	460	514	709
Crop tree spacing (m)	4.27	4.27	3.66
When d.b.h. of 25.4 cm attained			
Tree age (years)	74 to 78	60 to 66	69 to 70
Tree height above stump to apical tip (m)	12.8 to 13.4	13.7 to 14.0	17.4
Height aboveground to base of live crown (m)	6.10	6.40	9.14
Diameter inside bark at breast height (mm)	243	243	243
Diameter inside bark at base of live crown (mm)	193	190	161
Stemwood volume from 152 mm-high stump top to apical tip (m^3/tree)	.318 to .334	.342 to .350	.439

These stands thinned at 30 years and clearcut when the crop trees have attained 25.4 cm d.b.h. will have average annual increment of all stemwood harvested (thinnings plus crop trees to apical tip) of about 2.6 m^3 per ha per year on the poorest site, about 3.8 m^3 per ha on the medium site, and about 5.7 m^3 per ha per year on the best of the three sites.

Built into the foregoing model predictions are growth inhibitions from moderate occurrence of dwarf mistletoe, root rots, and canker diseases in the plantations. It is assumed that the plantation will be protected from fire and that mortality from bark beetle attack, windthrow, and animal damage will be minor.

The foregoing estimates of annual increment compare reasonably closely to those tabulated for British Columbia and Alberta by Brand and Penner (1991).

In closing this brief discussion of growth, yield, and harvest, I should note that to favor wildlife (at some diminution of scenic values) it would not be difficult or particularly costly to leave dead snags standing during clearcut harvest, and to leave a relatively small tonnage of larger wood of low grade on the ground.

Opposing the desire to leave significant tonnages of larger roundwood on the ground are the following considerations:

- Loss of merchantable product, and in-place utilization standards of land managers that militate against leaving residual wood of size sufficient to yield a product (for example, a 2 by 4 stud)
- The public's dissatisfaction with a site littered with waste wood (surveys clearly show that the public favors a clean site)
- Increased difficulty of site preparation to enhance regeneration (for example, roller chopping) caused by large tonnages of residual roundwood

Carbon Sequestration

Chadwick D. Oliver, among others, notes that the given amount of carbon in the world exists primarily either as carbon dioxide in the atmosphere or as "storage" in living and formerly living things. Carbon is taken out of the atmosphere and put in "storage" in organic compounds by photosynthesis. The storage can be in several forms:

- Living and recently living plants and animals
- Fossil fuels such as coal, oil, and natural gas
- Limestone and marble, from marine plants and animals

Carbon is returned to the atmosphere by reduction of one or more of these "storage centers." This reduction can be by decay, combustion, respiration, and dissolution (of calcium carbonate). Concern exists that carbon is being moved out of storage and into the atmosphere more rapidly than it is being taken out of the atmosphere and put into storage, resulting in an increase in carbon dioxide in the atmosphere—and posing the threat of global warming.

Combustion, which is the rapid chemical combination of oxygen with the elements of fuel that will burn, is one of the major sources of atmospheric carbon dioxide. Chemically, it is an oxidation process that results in the release of heat energy. The major combustible elements of wood and bark are carbon and hydrogen. The complete oxidation of carbon forms carbon dioxide and heat energy; complete oxidation of hydrogen yields water and heat energy. But combustion of wood and bark is not always complete, which results in release of lesser amounts of carbon monoxide, hydrocarbons, and other substances.

What then is the tradeoff between burning a stand in a wildfire and harvesting the stand for conversion to wood products for incorporation into structures? The biomass consumed by wildfire releases resulting carbon dioxide to the atmosphere; biomass killed by the wildfire, but not combusted or removed in salvage harvests, decays and thus releases more carbon dioxide to the atmosphere. In contrast, clearcut harvesting for wood products leaves a relatively small portion of the biomass on the acreage to decay, or possibly to be burned during site preparation for regeneration. Of the wood and bark removed from the site, about 50 percent is converted to solid-wood structural products that may be sequestered in a building for perhaps 200 years before demolition and recycling. Only about 27 percent of the mass of incoming logs with bark, in typical lumber mills, ends as fuel to generate power and process heat for the lumber mill or for the pulp mill that purchases the coproduct pulp chips. About 15 percent ends as a paper product and about 8 percent as particleboard.

Ultimately, the solid-wood products, the particleboard products, and the paper products decay or are combusted, thus returning the carbon sequestered therein to the atmosphere. In the meantime, however, release of carbon dioxide to the atmosphere has been significantly delayed compared to the prompt carbon dioxide release caused by wildfires.

Erosion and Water Quality

Destruction of trees and ground cover by intense wildfire can drastically increase both mass and surface erosion. The literature, while not unanimous in findings, generally concludes that intense fires increase bulk density of soils and decrease soil infiltration rates, porosity, and organic matter content. Many studies report detrimental erosional effects of forest denudation by fire including increased flooding, erosion

from bare slopes, and sediment loading in streams—and in many cases slope failures or land slumps and great debris flows (Striffler and Mogren 1971).

Thompson's (1964:110) description of the effects of intense wildfires in the steep Salmon River country of the Bitterroot-Selway wilderness area is particularly graphic:

> The plague of fires in this type of wilderness area, besides loss of winter game range, is mud rock flows as a result of torrential rains falling on a burned-out drainage. In these cases, deep, steep-sided gorges are scoured out. Some of these could not be crossed by man or beast after 25 years. The deposition of mud, rocks and timber in the main river channels seal salmon and trout spawning gravels for years to come. In this climate it is estimated to require over 100 years to restore a stable channel and rebuild fish food habitat.

In the postfire period on a large burn there is high potential for watershed damage. Lyon (1984) observed on the Sleeping Child burn in western Montana that the burned sites were vulnerable for at least the first 2 years; thereafter native vegetation provided cover in the 10 to 15 percent range. Rehabilitation by aerial seeding doubled ground cover during this early period, but actual cover values were low. During the first postfire growing season on this burn, live cover was less than 5 percent, but half of that was supplied by introduced species (Lyon 1984).

Unless protected by more or less extensive shortgrass meadows, control of stocking density, and prevention of fuel build-up, even wetland and riparian areas in the steep headwaters of lodgepole pine forests may be swept and burned out by intense wildfires following tree mortality from bark-beetle attacks. Ensuing autumn rains and spring run-off of snow can significantly—if temporarily—alter riparian habitats so affected. And these wetland and riparian habitats hold concentrations of perhaps three-quarters of the wildlife populations of the lodgepole pine forest.

Erosion and watershed damage caused by wildfire are largely uncontrollable. While harvesting operations of thinning and clearcutting can also cause erosion and watershed damage, such alteration can be largely controlled. That is, best management practices in riparian areas coupled with intelligent placement of roads and skid trails to minimize soil disturbance can greatly reduce erosion and stream sedimentation caused by harvesting activities.

Forage

Cattle, horses, and sheep find little to eat in fully treed lodgepole pine forests—particularly in those stands with closed canopies and dense stocking. While a wide range of plant associations exist in the various densely stocked pine habitats, few afford an amplitude of grasses, forbs, and shrubs palatable to cattle, horses, and sheep. Moreover, as horseback riders familiar with crosscountry travel in lodgepole forests can attest, the dead and down wood in many stands is a formidable barrier to grazing by domestic livestock. Additionally, because lodgepole pine forests typically occupy deep-snow country, available forage is accessible to livestock and ungulate wildlife only from late spring to late autumn—perhaps 5 months per year.

Forage suitable for domestic livestock in lodgepole country is principally found in such forest openings as natural meadows, marshes, prairies, untreed slopes, grassy stream banks, stringers of open timber types, or in temporary openings caused by wildfire, prescribed fire, or harvesting activity with its associated roadsides, landings, and clearcuts or thinned acreages. Sparse stands of lodgepole also provide significant production of forage.

Responses of Forage Vegetation to Fire

Fire affects not only the lodgepole pine overstory but also succession in the understory. Mature lodgepole pine forests of the Northern Rocky Mountains typically are composed of dominant overstory pines with an understory of shade-tolerant shrubs and herbs. Relationships between the overstory and understory exhibit a full range of dominance patterns, but often an inverse relationship exists between understory density and overstory crown closure.

Lyon (1971) modeled succession following a prescribed fire in Neal Canyon near Ketchum, ID, in which a significant component of the forest was lodgepole pine. The fire was of sufficient intensity to produce crown fire and tree mortality. In his depiction (fig. 13) of the theoretical postfire development of the vegetal community, growth of herbaceous vegetation peaks in the first decade, shrubs peak toward the end of the second decade, and trees later suppress growth of both as tree canopy closure reaches 100 percent.

Responses of Forage Vegetation Following Harvest Activity

Growth of most understory forage species increases with increasing light. Therefore, tree-crown cover has a major influence on, and is linearly correlated with, herbage production. The specifics of the relationship obviously vary with habitat type, but the principle has been observed in two lodgepole pine forests in central British Columbia (Dodd and others 1972) and in lodgepole stands in the Gallatin and Lewis and Clark National Forests of Montana (fig. 14).

As is the case with openings created by fire, the increases in forage production in clearcut openings usually persist for 10 to 20 years before competition from tree reproduction begins to reduce understory

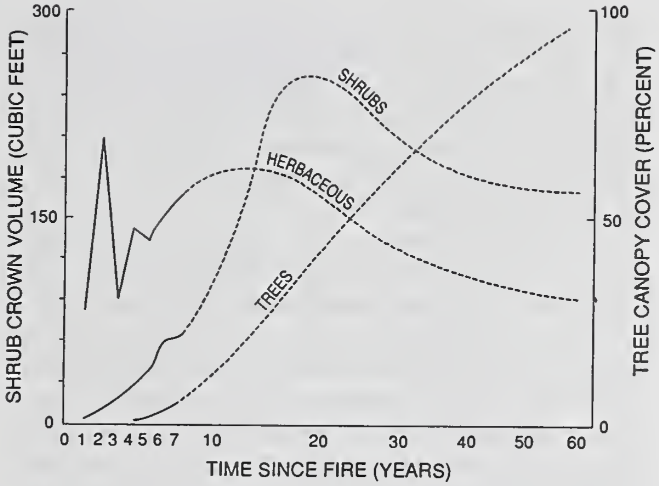

Figure 13—Theoretical development of Neal Canyon vegetal community from the postfire year to 100 percent crown closure 60 years later. Drawing after Lyon (1971).

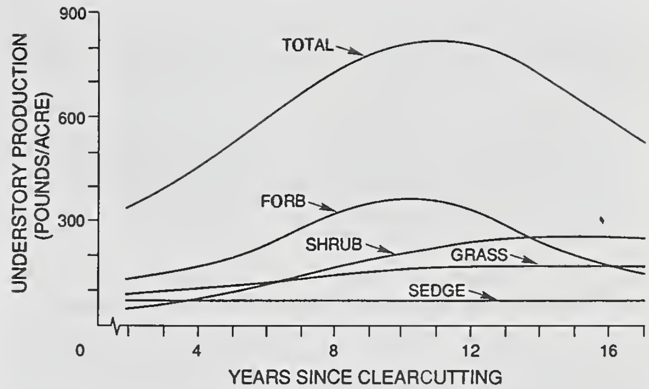

Figure 15—Trends in understory production on Montana lodgepole pine clearcuts related to time since tree harvest. Drawing after Basile and Jensen (1971).

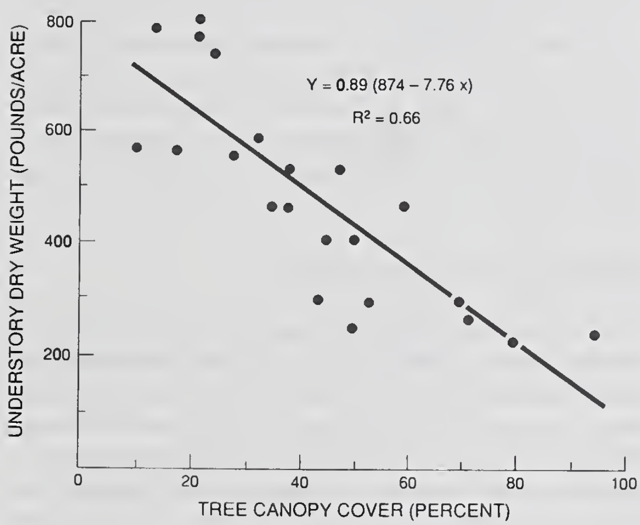

Figure 14—Lodgepole pine tree canopy cover related to dry-matter production of understory vegetation. Data taken in Montana's Lewis and Clark and Gallatin National Forests. Graph is is based on data from T.M. Conway, as interpreted by Hungerford (1987).

vigor and composition (fig. 15). Postharvest species composition may or may not differ significantly from preharvest composition depending on habitat type.

Production can be maintained only by frequent thinnings and intermediate cuts that keep stock levels low. For example, Lyon (1987) estimated that a 66 percent thinning treatment (from a closed canopy situation) of lodgepole pine in the Northern Rocky Mountains of the United States could possibly result in an understory response that will increase forage production for big game, but a 33 percent reduction in canopy cover will likely not result in a productive understory.

Psychology and Scenery: Two Aspects of Recreation

Stankey (1989) observed that humankind's earliest records reveal a duality of attitudes about wilderness. Nowhere is this duality more clearly expressed than in Judeo-Christian biblical passages. In discussing the historical roots of the wilderness concept, Stankey (1989:10) commented:

> [In biblical literature] wilderness is a synonym for desolate, wild, and uninhabited lands manifesting God's displeasure. But wilderness also served an important function in Christianity as a place where one could prepare for contact with God. Such contrasting perspectives created an ambivalence that still prevails. Yet despite the ambivalence, early European and North American societies perceived wilderness as a threat.

By the end of the 20th century, however, psychological and physical fear of wilderness was much diminished in North America, and the concept of spiritual renewal through wilderness experience became dominant. Today in North America, the desire to roam an untrammeled forested wilderness—however unrealistic such a desire may be for many people—is part of the American psyche, and the freedom to so roam is part of our heritage. It is understandable, therefore,

that strong concern about forest environment exists. As Alston Chase (1995) observed in his book *In a Dark Wood*:

> For most people, worry over the environment springs from the heart, not from theory. It is a legitimate response to the soul-destroying ugliness and overcrowding of cities and suburbs and to America's inability to stop the spread of this blight into the countryside.

For many, dreams of escape from urban complexities and desires for spiritual renewal focus on forests adjacent to the crest of the Continental Divide in western North America. And it is in this region that lodgepole pine is most abundant.

Scenic expectations about commercial forests are usually different from scenic expectations about forests in National Parks or designated Wilderness Areas. Visitors are usually—but not always—less sensitive to human-caused perturbations in commercial forests than to human-caused perturbations in wilderness areas.

Even in commercial lodgepole pine forests, a major aspect of recreation is enjoyment of the grand scenery and viewscapes typical of the country where lodgepole pine grows. Only a small fraction (less than 10 percent) of recreationists in lodgepole country stay overnight away from their vehicles or away from roadside camp grounds or habitations (National Park Service 1991a, 1991b). That means an overwhelming majority of the recreationists observe only the scenery visible from towns, highways, roads accessing the forest, waters fishable or floatable on day trips, and trails prepared for snow machines, off-road vehicles, and day use by hikers and horsemen. Airline passengers see a broader landscape, usually from high altitude. While foresters see beauty in all stages of a managed forest, most viewers focus only on the immediate visual effect of perturbations, and exhibit small appreciation for anticipated later stages of development—however well planned.

In a study specific to lodgepole pine, Benson and Ullrich (1981) found that in forest landscapes people like natural and orderly scenes as opposed to disturbed, disorderly ones, and that revegetation and tree growth following disturbance improve viewers ratings over time.

In lodgepole pine forests, three major types of perturbations strongly affect scenic values: insect attacks, wildfire, and harvest.

Insect Attacks, Fire, and Scenery

Buhyoff and others (1982) noted that the negative scenic impact of damage from mountain pine beetle is greatest on vistas characterized by little topographic variability, areas of restricted or narrow view of more distant features, and sparsely forested areas.

Benson and Ullrich (1981) concluded that viewscapes with mature lodgepole pine forest with a meadow edge in the foreground gained high ratings, whereas a decadent lodgepole stand with beetle-killed dead, dying, and down timber received low ratings. To enhance visual aesthetics, the sooner dead lodgepole pine is regenerated, the better.

Most visitors view forests blackened by fire with distaste (Polzin and others 1993), although rapid greening of grass and other undergrowth in the year or two following the fire ameliorates this distaste. But unsightly and hazardous blackened stems usually persist for many years, and natural regeneration of lodgepole seedlings may well require a decade to reach breast height. The distaste of wilderness visitors for a fire-blackened landscape is evident in the precipitous drop during 1989 and 1990 in visits to the Scapegoat Wilderness area of Montana following the extensive wildfire of 1988. Polzin and others also observed that visitations to Yellowstone National Park decreased significantly in the year of the big fires (1988), and visitation rate of growth slowed significantly in 1989.

Salvage harvests following extensive wildfire are usual where economically feasible. Interestingly, and in my view unfortunately, the traveling public frequently, and incorrectly attributes the substantial scenic damage from wildfire or beetle kill and subsequent salvage to humankind's rapacity instead of nature's will.

Harvesting and Scenery

Because only a small percentage of recreationists stay overnight in back country, most of them judge timber management activities by what they see during travel along forest roads. Landscapes are enhanced by road routing to provide visual variety in the travel sequence along the road. Efforts to make individual sales aesthetically pleasing must take into account other sale activities in the area.

Viewers polled by Benson and Ullrich (1981) found the harvesting regime in which the understory was cut and residue removed more attractive than unthinned stands. Similarly, in many cases small edge-contoured clearcuts can be visually attractive if residues remaining on the site are not obtrusive and if the clearcut is melded into the overall landscape design. The less logging debris, the higher the preference. Aesthetic ratings improve with time following clearcutting of lodgepole pine but ultimately decline as stands become overmature.

Wildlife

While wildlife literature is extensive on some subjects, it insufficiently addresses the subject of wildlife

in the lodgepole pine forests of North America, particularly as affected by the periodic perturbations of habitat previously described. Future managers of lodgepole pine forests that are climax, or can be managed as climax forests, need knowledge of the effects on wildlife of wide-scale beetle-caused mortality and subsequent stand-replacing wildfires—particularly in comparison to the effects of those perturbations caused by precommercial thinning, mid-rotation commercial thinning, and rotation-age clear-cut harvesting.

Managers of extensive stands of lodgepole pine are accustomed to measuring the forest outputs more or less precisely: streams are gauged for outflow during spring runoff and during summer drought; forage yields are monitored by clipping samples at suitable intervals; annual recreational use is determined by counting numbers of summer hikers, autumn hunters, and winter skiers; and standing volumes of wood are periodically inventoried to permit computerized modeling of growth and yield.

But seekers of information about the population distribution and density of wildlife species by county or other geographic or political entity are frustrated by the absence of similar data. Admittedly this population will vary by season and from year to year. For example, in the Lolo Creek and the Lochsa and Selway River drainages of western Montana and northern Idaho, hunters today come from all over the United States to hunt the elk and other large game animals that are plentiful there. Yet in 1805 members of the Lewis and Clark expedition—skillful hunters all—in their east-to-west crossing of the area grew lean and hungry for want of game. Edwards (1956) correlated much of such variation in ungulate populations to winter snow depth and severity. Large-scale wildfires are another major influence; while they may cause temporary declines in ungulate populations, increases are generally observed in the two or three decades following.

Understandably, much of existing habitat research is local, or at best regional. Yet wide latitudinal and elevational variations are evident in wildlife populations and in their reactions to habitat changes. The native grayling populations in the cold, clear water of the Deese River in western British Columbia no doubt react differently to stream and streamside perturbations than do the grayling (or the introduced brown trout) of the summer-warmed Big Hole River in Montana. The elk in the high lodgepole pine forests of the Yellowstone ecosystem and in the Sapphire Mountains of western Montana must react differently to habitat changes than the moose and mountain caribou of more northern latitudes and lower elevations in British Columbia. The snowshoe hare populations in the lodgepole pine forests of south-central British Columbia and western Alberta must react to change differently than do those of snowshoe hares of the high Bitterroot Mountains of Montana because the former go through a 10-year cycle of population growth and decline, while the latter do not. Is the lynx that favors the lodgepole pine forests of northeastern Washington more sensitive to habitat perturbations than the more widely distributed mountain lion that is also found in lodgepole pine stands?

Such questions covering a wide range of wildlife species need to be answered.

Throughout all the lodgepole pine forest, various wildlife species may be transient. Anadromous species of salmon move in and out of many headwater rivers of the lodgepole pine region in migrations that have been going on for thousands of years. In many areas eagles migrate to follow the salmon to their spawning grounds. Elk and mule deer move to high-elevation ranges in summer and descend to lower and warmer ranges with the onset of winter. Chickadees, Clark's nutcrackers, spruce grouse, and squirrels may reside the year around within particular stands of lodgepole pine, but ducks may be only briefly transient in ponds and marshes in lodgepole pine forests as they move from northern nesting areas to southern latitudes for the winter. Coyotes, whose population fluctuates with fluctuating populations of rabbits, voles, and mice, may have fairly restricted ranges within the forest, although if food is scarce will leave for more favorable habitat. Grizzly bears, on the other hand, routinely wander hundreds of miles during their search for food and desirable habitat.

In short, understanding of these populations and their reactions to habitat changes will always be incomplete, but some knowledge is better than none.

Wildlife Management Objectives

A major objective of wildlife management is maintenance of wildlife diversity, which has been defined as the diversity of life, including the diversity of genes, species, animal communities, ecosystems, and the interaction of these communities. Most would contend that the biodiversity concern is not about the local diversity of flora and fauna, but whether species or ecosystems are threatened. Another way of stating the objective is to keep common species common while simultaneously maintaining or recovering populations of rare or jeopardized species.

Influencing the pursuit and attainment of these objectives is knowledge that species extinction is a natural process that, when extended over geologic time, has periodically caused major reductions in diversity. In modern times, habitat destruction, over exploitation, and impacts of exotic species are the most

important causes of extinction (Langner and Flather 1994).

Oliver (1992) observed that maintaining stable populations of all species by managing for each species individually is an impossible task. However, biodiversity can be promoted by maintaining the habitats of appropriate spatial and temporal scale—forest structures—in which various species are found. And silvicultural operations can maintain a target distribution of such structures across the landscape. Lodgepole pine persistent and climax forests in various age classes, would be just one component of such target distributions across a larger landscape, where other forest types would go through successional stages of stand initiation, stem exclusion, understory initiation, and multistoried old growth.

McMinn (1991) concluded that biodiversity was often in the past erroneously understood to mean species diversity within stands or communities, probably because that has been the most common use of the term "diversity" in the literature. But the once widely accepted theory that ecological community stability is positively related to diversity is currently seriously questioned. Much ecological evidence suggests that the relationship of ecological community stability to diversity is unpredictable and variable. Thus, ecologists no longer assume that high species diversity ensures ecological community stability.

The literature also suggests that the simplest characterization of diversity—a species enumeration—has limited usefulness without inclusion of some measure of how evenly abundance is distributed among the various species.

The lack of quantitative data on the density of wildlife populations within the lodgepole pine forest has frustrated both neophytes and professionals.

Species Richness

Discussing the needs of individual wildlife species within lodgepole pine ecosystems is beyond the scope of this paper. But some broad-scale quantitative data on species richness are available. In the United States, summary publications describe wildlife in lodgepole pine forests in the Blue Mountains of Oregon and Washington (Thomas, editor, 1979), Colorado (Hoover and Wills, editors, 1984), and California's Western Sierra Nevada (Verner and Boss, technical coordinators, 1980).

In the Foothills Forest, adjacent to Jasper National Park, radio collars are in use to study the seasonal requirements of the site's elk and caribou. A report to Parliament by the Canadian Forest Service (Natural Resources Canada 1994) indicates that computerized forest models are being developed to establish timing and location of logging operations, while at the same time ensuring that the animals have enough habitat for their needs throughout the year. The study should ultimately yield data on the density and distribution of elk and caribou in this area containing significant volumes of lodgepole pine.

Currently, however, the Canadian literature provides no publications broadly descriptive of wildlife species richness, distribution, and density within the lodgepole pine forest type in British Columbia, the southern portion of the Yukon Territory, and the western portion of Alberta.

Illustrative of the types of studies that, in my view, are needed is that by Sullivan (1996). His study provided data on variations in populations of red squirrels (*Tamiasciurus hudsonica*) and variations in diversity of small-mammal species richness as affected by degree of thinning intensity in lodgepole pine stands of British Columbia. The factorial study was replicated at three different latitudes, with variables as follows:

- Stand age: 17 to 27 years
- Stand locations: Penticton (49½° latitude); Kamloops (50½° latitude); Prince George (53¾° latitude)
- Stand densities: thinned to 500, 1,000, or 2,000 trees per ha, as well as natural unthinned and old growth stands
- Years studied: 1991 and 1992

Sullivan observed that in May, June, July, and August, populations of red squirrels were lowest in stands thinned to 500 stems per ha. The circumstances in which red squirrel populations were greatest during these months varied with thinning regime and with location, as follows:

	Approximate stems per ha
Penticton	1,000
Kamloops	2,000
Prince George	2,000

When diversity of small mammals was considered (including northwestern chipmunks, shrews, deer mice, jumping mice, long-tailed voles, red-backed voles, meadow voles, and weasels) results again varied with location and thinning intensity, as follows:

- Penticton: No significant differences were observed in small-mammal diversity among stands except that in 1990 the communities in old growth tended to be more diverse than those in the medium density stand.
- Kamloops: Small-mammal diversity was significantly greater in all thinned stands than in unthinned and old-growth stands in 1990; this trend of greater diversity continued in 1991 for the low and medium-density stands.

- Prince George: In 1990 the low- and medium-density stands tended to have greater diversity of small-mammal species than the old-growth stand; in 1991 all thinned stands had greater diversity of small mammals than the unthinned stands, and the low-density stand had higher diversity than the old-growth stand.

Sullivan concluded that stand thinning did not negatively affect diversity of understory vegetation or small-mammal communities. In fact, the thinned stands tended to have greater overall diversity than the unthinned stands, with diversity greatest in stands thinned to lowest density.

Ecological Implications of the 1988 Yellowstone Wildfires

Fire, controlled or uncontrolled (or a harvest alternative), alters vegetation and its succession and therefore affects wildlife distribution and abundance. In his study of fire's influence on wildlife habitat in the Bridger-Teton National Forest in Wyoming, Gruell (1980) observed that management of wildlife must become vegetative management to be successful over the long run. This generalization is true for all species of wildlife. Thus, the role of fire and harvesting activities must be considered.

Because carnivores depend on herbivores for food, successional changes that favor herbivores such as small mammals, mule deer, and moose may also favor certain carnivores. For example, Edwards (1954) concluded that an intense wildfire in British Columbia's Wells Gray Park covering 520 km^2 created—at the expense of mountain caribou habitat—new habitat for wolverines, wolves, and grizzly bears, and allowed mountain lions to become common and coyotes to flourish 30 years after burning.

In the United States, the 500,000 ha Yellowstone fires of 1988 also provided a good opportunity to study the effects of stand-replacing fires on the wildlife habitat of climax lodgepole pine forests. The papers of the Second Biennial Conference on the Greater Yellowstone Ecosystem held 19-21 September 1993, and abstracted in Despain and Schullery (1993), provide insight into some effects of broad-scale stand-replacing fires in climax forests of lodgepole pine. The remainder of this section is derived from that conference proceedings.

Aquatic Ecosystems and Fisheries—Debris-laden flows from watersheds burned by moderate fires carried one-half to one-seventh as much sediment and water as did those from severely burned canyons. Elevated sediment loadings in streams affected by fire continued (at least through 1992 observations), with a majority of sediment being caused by short-duration high-intensity storm events in intensely burned areas.

In Jones Creek, a burned watershed, numerous dead trout displayed symptoms of suffocation following a debris torrent from high stream flows caused by a 1990 thunderstorm. In more placid rivers at lower elevations, peak streamflows occurred about 2 to 4 weeks earlier than usual, and the amount of aquatic vegetation increased considerably in half of the streams by the second year postfire. Water quality, however, was in the range of prefire variability, and with the exception of the Gibbon River, microinvertabrate communities did not decline in abundance or diversity. Electrofishing and angler data failed to reveal any negative effects on fish populations in these lower river sections.

Long-term water quality records for Yellowstone's major lakes have not shown any discernible shift in quality, and analysis of Yellowstone cutthroat trout populations in Yellowstone Lake did not detect changes that could be attributed to the wildfires.

Large-Animal Mortality—There were 396 confirmed large mammals killed from fire-related causes within the Yellowstone ecosystem during the fire season of 1988, of which 84 percent were elk. The balance of fire-kills were mostly mule deer and moose, with lesser percentages of bison and black bears. Smoke inhalation was the primary cause of mortality.

An estimated 3,021 to 5,757 additional elk died from winter malnutrition, and another 2,773 were harvested during the severe winter immediately following the fires, or about 38 to 43 percent of the elk herd. Some investigators postulated that because of poor forage growth in the dry summer of 1988 combined with the severe 1989 winter, a large segment of the mortality in 1989 would probably have occurred without the 1988 fires.

The literature strongly indicates the long-term benefits to ungulate populations from large-scale wildfires. For example, the large Northern Rocky Mountain forest fires between 1910 and 1920 burned nearly 2 million ha of forest land in northern Idaho and western Montana. Within 30 years the recovering seral vegetation produced a big game population greater than any in recorded history of the Northern Rockies. According to wildlife specialist Daniel Pletscher, populations of elk in Yellowstone National Park have recovered from losses during and shortly after the 1988 wildfires so that populations are now at least as great as in prefire days.

Effects on Moose Range—Moose are typically associated with early successional stages and generally benefit from forest canopy removal. However,

prefire and postfire comparisons in Yellowstone National Park of habitat selection, diet, home-range size, and populations indicated that moose did not benefit from canopy removal and expressed avoidance of areas where this had occurred. This included areas burned in 1988 (where admittedly vegetation had little time to respond after the fires), but also areas logged as long as 40 or more years before the data were collected. The browse species most prevalent in their diet were found in older forests. The older forests also provided the most favorable traveling conditions by shading the snow pack to prevent a crust from forming and by filtering out falling snow.

Effects on Grizzly Bear Range—On average, grizzly bears used burned habitats in proportion to their availability within individual annual ranges during 1989 to 1992. Seasonal indices of movement and annual range sizes of cohorts were not statistically different from the 1975 to 1987 averages.

Cavity-Nesting Birds—Following the 1988 fires, populations of three-toed woodpecker species did not sharply increase as predicted, especially in the large-scale, high-fire-intensity areas. Lewis woodpeckers pioneered new areas, consequently expanding their range. An increase apparently occurred in cavity-nesting waterfowl (Barrow's goldeneyes and buffleheads). As expected, bluebirds, swallows, kestrels, flickers, and a number of other cavity-nesting species appear to be on the rise.

Litter Invertebrate Community—Little doubt exists that burning had detrimental effects on litter fauna. Many types of litter arthropods were found in unburned habitats that were not found, more than occasionally, even after 2 years, in burned forest sites. Litter arthropod diversity, richness, and density were positively correlated with the number of standing dead trees on burned sites in early summer following the fires. For reasons unclear, seedling density became positively correlated with arthropod richness and diversity by mid-August of the year following the fires.

Proposed Action to Gain Better Understanding of Perturbation Effects

To enhance the literature specific to wildlife populations and distributions related to intensive management of lodgepole pine, and to outline and stimulate needed future research, I hope that a joint Canadian—United States symposium—"Wildlife in the Lodgepole Pine Forests of North America"—will be organized and staged before the end of the century. The symposium would draw on new research and the extensive literature related to wildlife in western forests, with expert interpretations to relate findings to lodgepole pine forests under intensive management.

The proceedings from such a symposium would provide knowledge and guidelines for future managers of those lodgepole pine forests that are climax, or can be managed as climax forests—particularly with respect to latitudinal and elevational effects of perturbations and situations as follows:

- After extensive mortality from bark-beetle attack (fig. 5 and 6)
- After wildfire (fig. 7 and 8)
- In overly dense young regeneration
- Following precommercial thinning (juvenile spacing) of regeneration to control stocking density (fig. 9)
- In 30 year old unthinned stands previously spaced at age 10 years
- After intermediate commercial thinning (fig. 10 and 11)
- At stand average d.b.h. of 25 cm (age less than 80 years)
- After clear-cut harvest of crop trees at or before age 80 years (fig. 12)

Conclusions

Lodgepole pine forests are major assets of both the United States and Canada (fig. 2, 3, and 4). The management of these forests deserves high priority in both countries.

When considering climax and persistent commercial forests (timberlands) of lodgepole pine—particularly of ssp. *latifolia*—and not considering Wilderness areas, National or Provincial Parks, or other reserved areas, humans will benefit more by intensive management (fig. 1B) of these forests than from the natural cycle (fig. 1A) of loss through insect kill and subsequent wildfire. Water quality, forage production, and scenic values need not be lessened by intensive management compared to the natural cycle. The life cycles of these forests managed by the two alternative methods do not differ greatly in time span—that is, about 80 years for intensive management, and perhaps 100 years for the natural cycle of beetle-kill and subsequent wildfire.

The unknown factor that deserves much more research effort is that of wildlife. Forest managers need to know the effects on all classes of wildlife of the natural perturbations of broad-scale, insect-caused mortality followed by stand-replacing wildfire, followed by natural regeneration, as compared to human-caused perturbations of early precommercial thinning of regeneration (juvenile spacing), commercial thinning at about age 30 years, and clearcut harvesting by age 80 years.

Forest statistics show that habitat over millions of hectares of lodgepole pine in western North America now goes through, and will continue to go through, drastic and periodic alterations. Perturbations such as those illustrated (fig. 5 through 12) not only significantly curtail availability of food (in the short run), hiding cover, and thermal cover, but also alter the microclimate at and near ground level.

A major purpose of this essay, therefore, is to stimulate aggressive research on the effects (including latitudinal and elevational effects) of all these perturbations, both natural and human-caused, on wildlife. The research should focus on these perturbations within lodgepole pine climax and persistent stands that are one component of a larger landscape mosaic, where other forest types go through successional changes of stand initiation, stem exclusion, understory initiation, and multistoried old growth. I hope that a joint Canadian-United States symposium can be scheduled near the end of the century to report progress on this research.

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Lodgepole pine (*Pinus contorta* Loud.) is a major asset of the United States and Canada. Where other tree species do not prosper, this species is thrifty in spaced even-age stands. When grown to diameters 25 cm or to tree ages 80 years, lodgepole pine is at risk of mortality from beetle attack and wildfire. Stands are best maintained by precommercial cleaning of regeneration, intermediate commercial thinning, commercial and clear-cut harvesting before 80 years. In stands so managed, water yields and quality, forage yields, and recreational values need not be more at risk than from insect-caused mortality and subsequent wildfire. Wildlife is affected by both natural and man-caused perturbations.

Keywords: energy, fire, growth and yield, habitat, harvesting, insects, timber, *Pinus contorta* Loud., recreation, regeneration, resource data, silviculture, water

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